Higgs' Degenerate Relatives

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work in progress with David McKeen and Maxim Pospelov

LHC NOW
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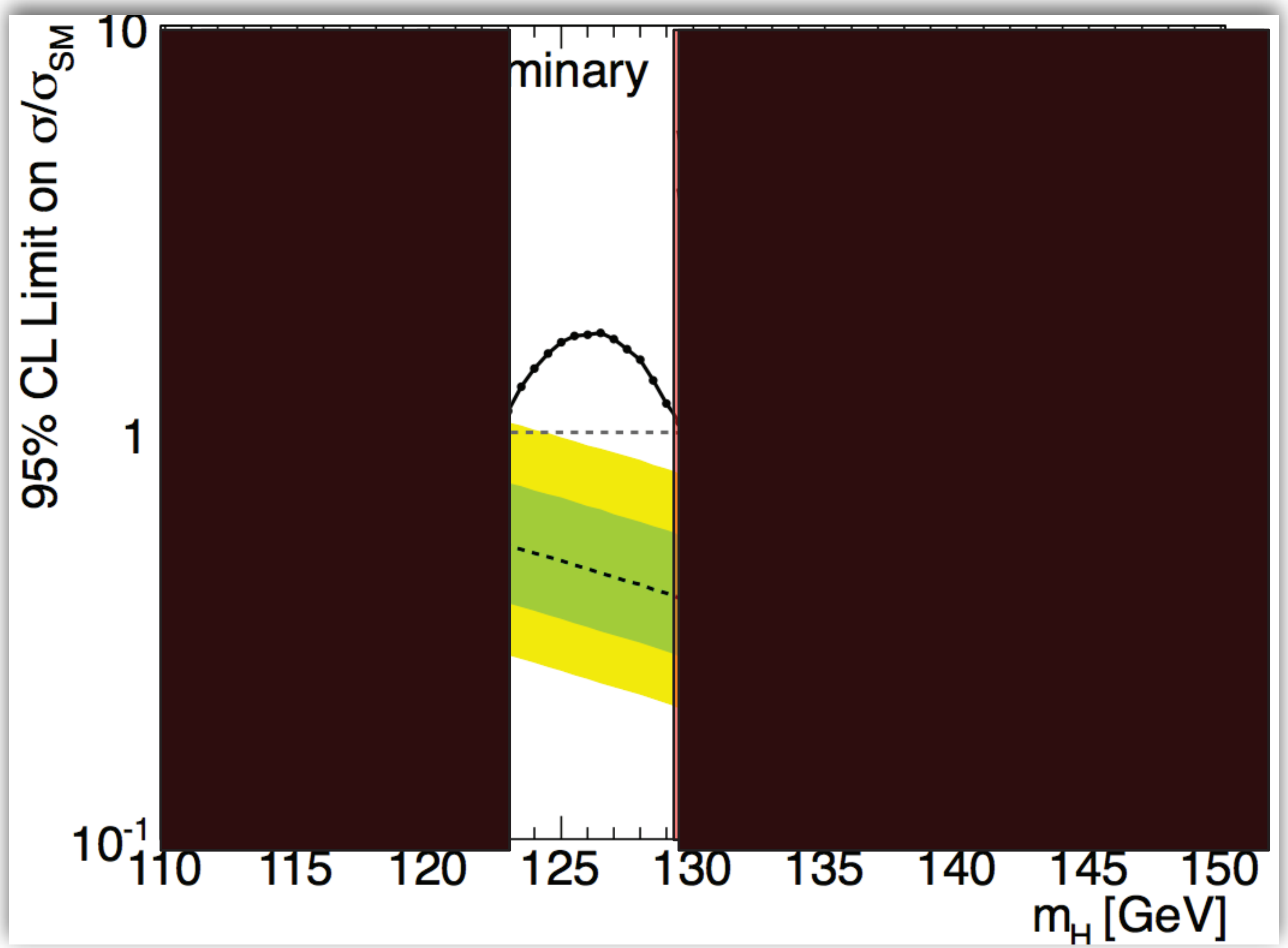
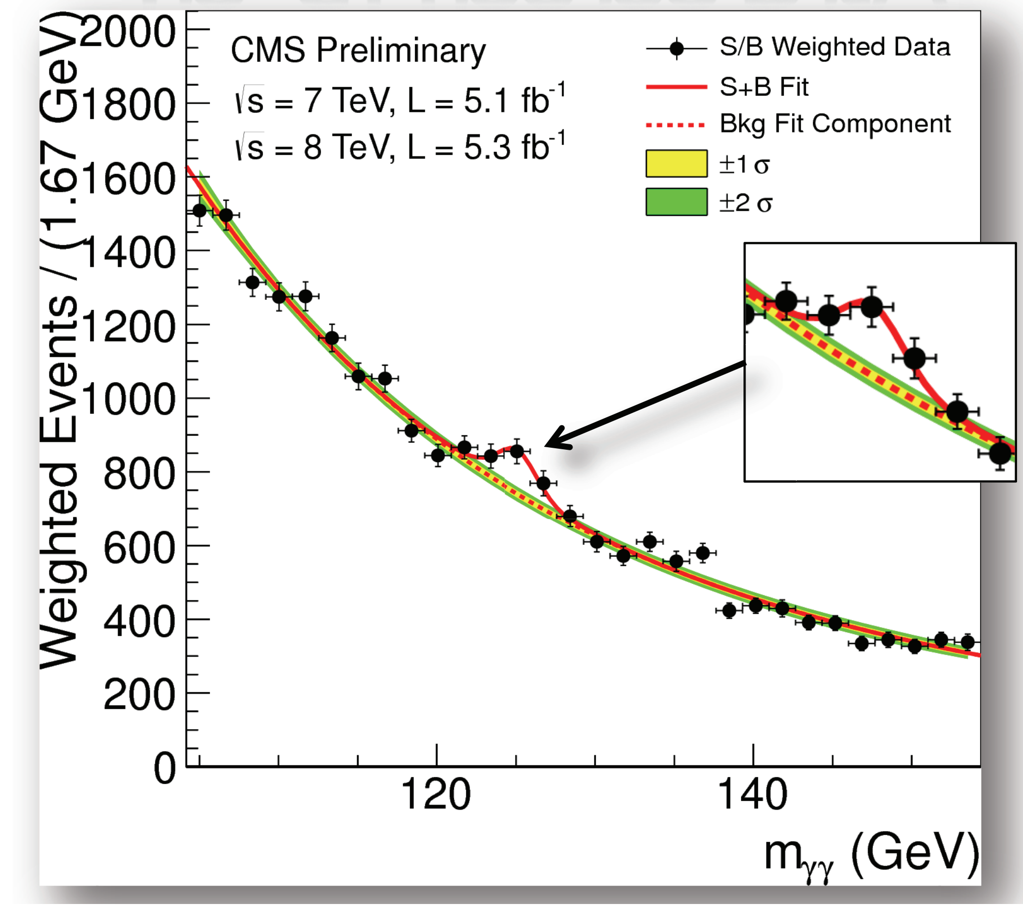
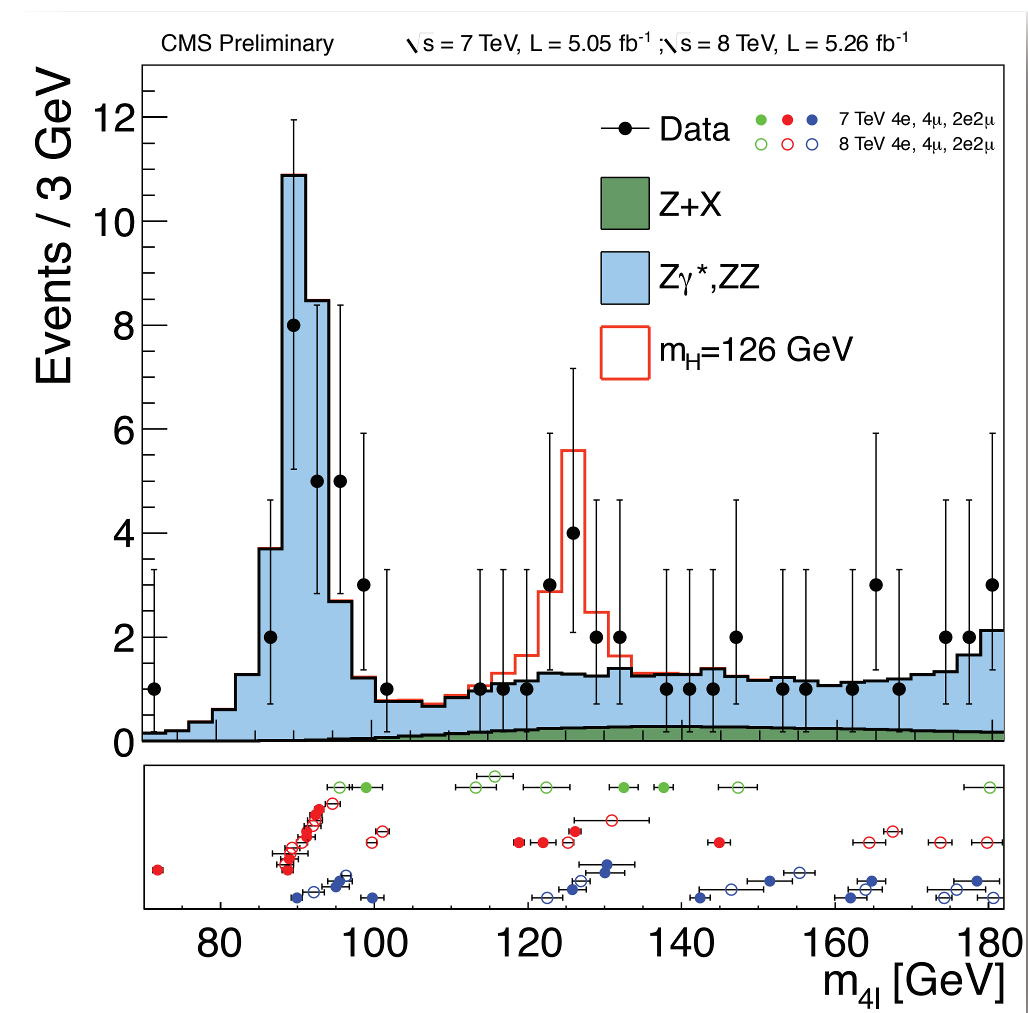
Higgs!


95% CL Limit on σ/σ_SM
10
1
10^-1
110 115 120 125 130 135 140 145 150
m_H [GeV]

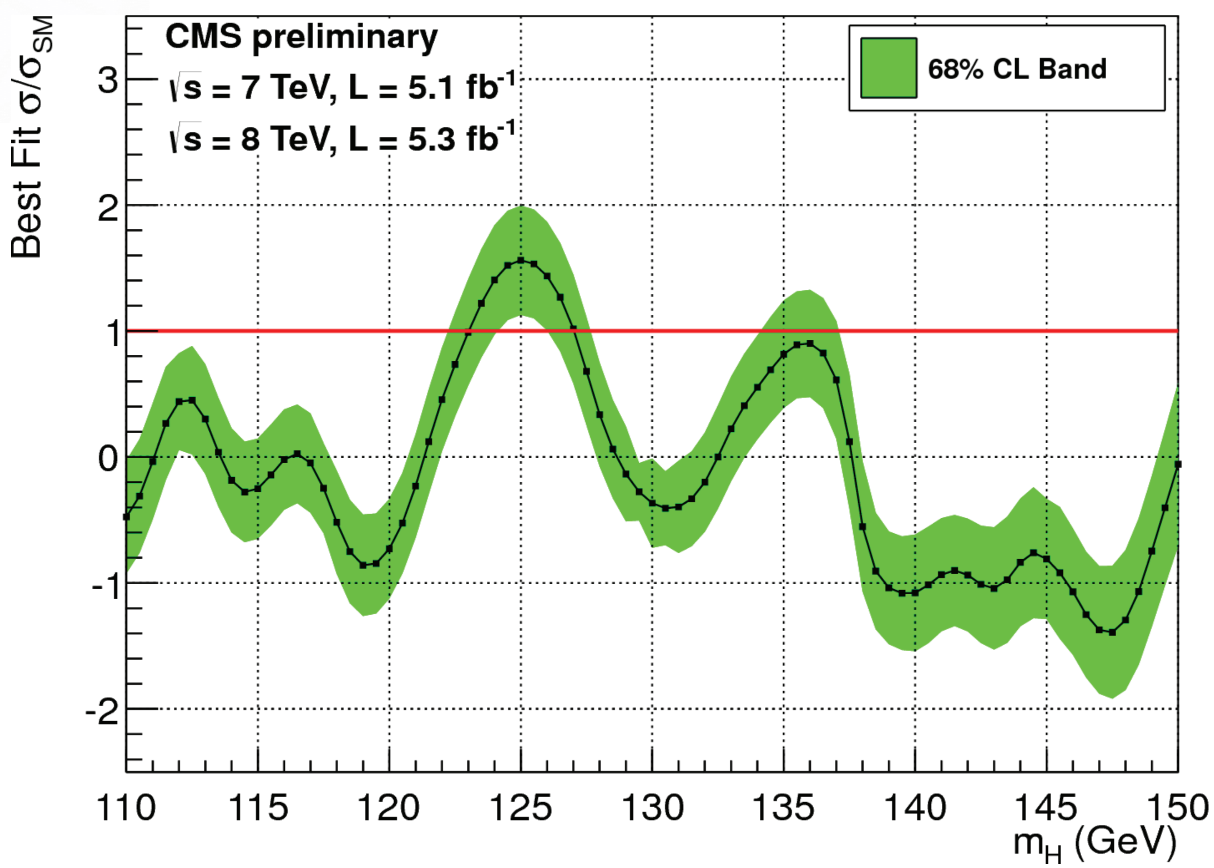

CMS Preliminary
√s = 7 TeV, L = 5.1 fb^-1
√s = 8 TeV, L = 5.3 fb^-1
S/B Weighted Data
S+B Fit
Bkg Fit Component
±1 σ
±2 σ
Weighted Events / (1.67 GeV)
0 200 400 600 800 1000 1200 1400 1600 1800 2000
120 140
m_γγ (GeV)

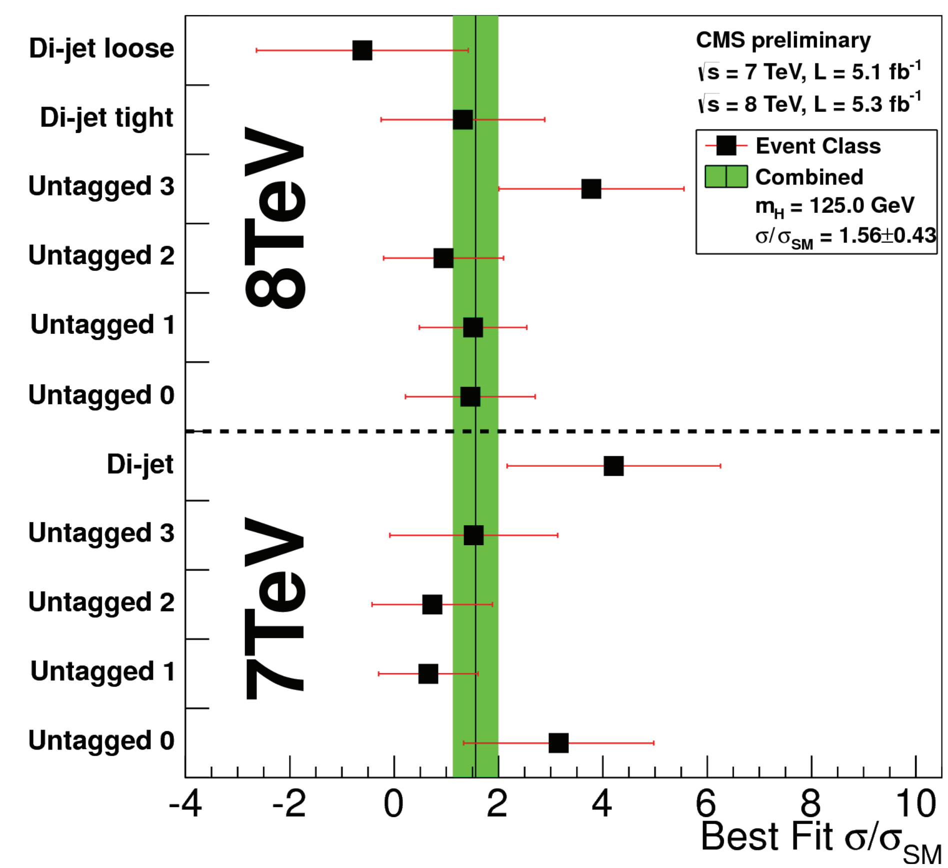

CMS Preliminary √s = 7 TeV, L = 5.05 fb^-1 ; √s = 8 TeV, L = 5.26 fb^-1
Data
7 TeV 4e, 4μ, 2e2μ
8 TeV 4e, 4μ, 2e2μ
Z+X
Zγ*,ZZ
m_H=126 GeV
Events / 3 GeV
0 2 4 6 8 10 12
80 100 120 140 160 180
m_4l [GeV]


OMFG HIGGS
www.omega-level.net

A few too many photons?

Fitted Signal Strength





Combined best fit signal strength
σ/σ_{SM} = 1.56±0.43 x SM, consistent with SM.

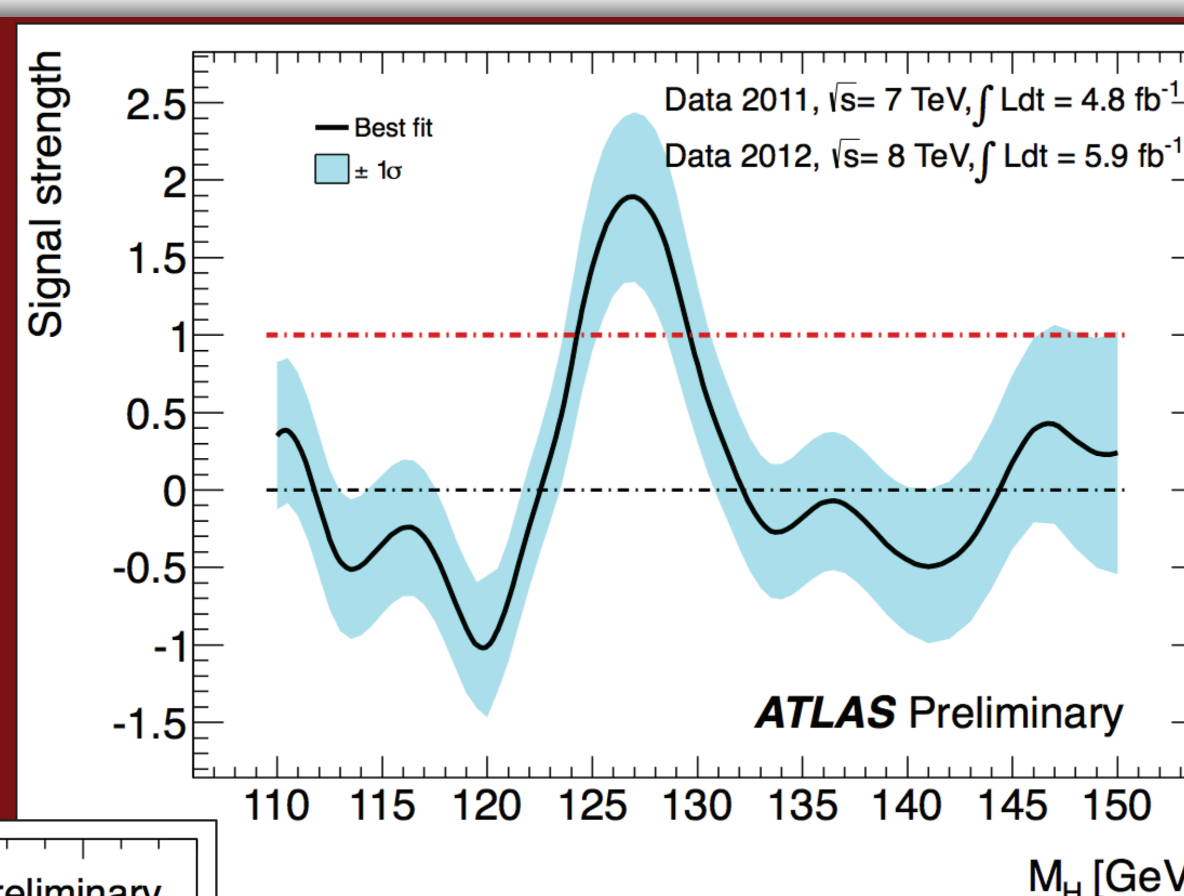
Best fit signal strength consistent between different classes

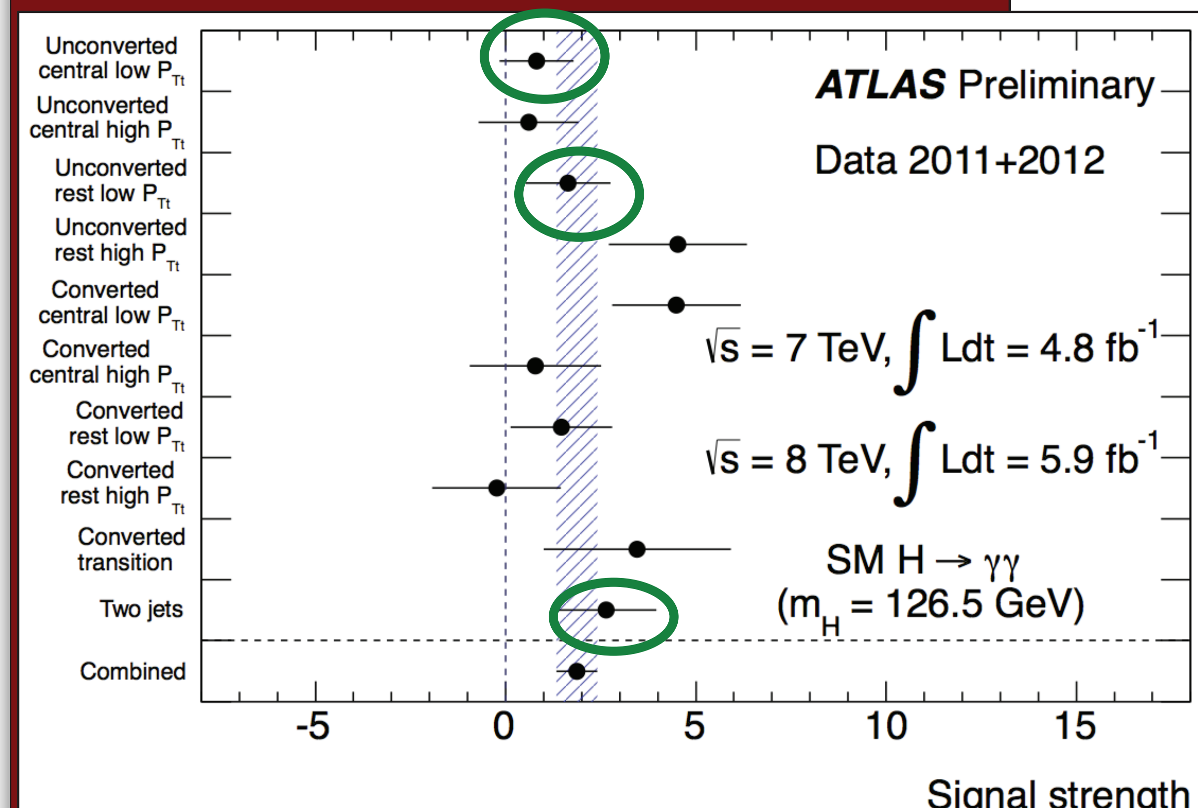
A few too many photons?

Fitted signal strength

Normalized to SM Higgs expectation at given m_H (μ)

Best-fit value at 126.5 GeV: μ=1.9 ± 0.5





Consistent results from various categories within uncertainties (most sensitive ones indicated)

How to enhance diphoton signal:

$$\sigma(pp \to h \to \gamma\gamma) = \sigma(pp \to h) \times \frac{\Gamma(h \to \gamma\gamma)}{\Gamma_h}$$

Couple Higgs to
new colored states

Reduce/change sign
of Higgs-top coupling

Reduce coupling of
Higgs to bottom quarks

Couple Higgs to
new charged states

Increase rate of Higgs production and/or
Increase rate of Higgs decay into a pair of photons

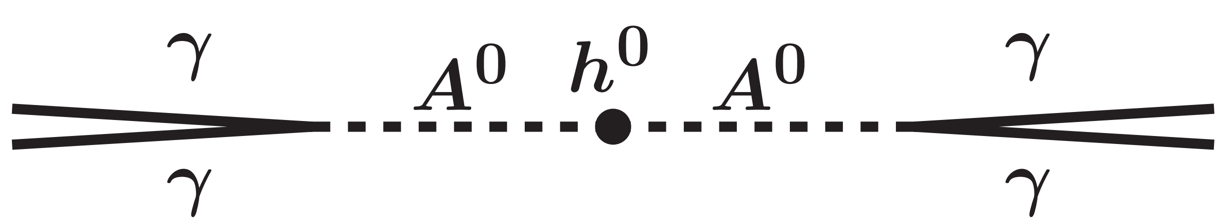
➡ Change couplings of Higgs to SM particles

Another approach: apparent enhancement

Essential feature: the process $pp \to h \to \gamma\gamma$ is not the origin of the extra photons; rather, a new state is!

An example: $h \to 2a \to 4\gamma$

Dobrescu Landsberg Matchev '00
Draper, McKeen '12
Roy, talk at Oregon Higgs workshop '12



Higgs has a small branching into a very light state which subsequently decays to a pair of highly boosted, collimated photons

Each photon pair reconstructed as a single photon, so as to mimic $h \to \gamma\gamma$

Apparent enhancement from a nearby state Y

h
Y $\}\ \Delta M \lesssim 1\ \mathrm{GeV}$

X

Y has its own coupling to photons or gluons

$$\mathcal{L}_Y \supset \frac{c_\gamma}{\Lambda} Y F F + \frac{c_\gamma}{\Lambda} Y G G$$

Splitting must be small
to preserve 125 GeV peak

3 cases:

Degenerate brother: mixing between Higgs and Y

Degenerate daughter: Higgs decays into Y

Degenerate mother: Y decays into Higgs

Degenerate brother

$$\left.\begin{array}{l} Y \\ h \end{array}\right\} \ \Delta M \lesssim 1\ \mathrm{GeV}$$

$$h \;\text{- - - - -}\overset{\theta}{\times}\text{- - - - -}\; Y \qquad\qquad \mathcal{L} \supset \frac{1}{\Lambda} Y F F$$

Requirements:

1. $\sigma(pp \to Y) = \theta^2 \sigma(pp \to h) \gtrsim \sigma(pp \to h) \mathrm{Br}(h \to \gamma\gamma)$

2. $\Gamma(Y \to \gamma\gamma) > \Gamma(Y \to h^*) = \theta^2 \Gamma_h$

$$\Rightarrow \quad \boxed{1 \lesssim \frac{\theta^2}{\mathrm{Br}(h \to \gamma\gamma)} < \frac{\Gamma(Y \to \gamma\gamma)}{\Gamma(h \to \gamma\gamma)}}$$

Minimal model

$$-\mathcal{L} \supset \frac{1}{2} m_Y^2 Y^2 + A H^\dagger H Y + y Y \bar{F} F$$

mass mixing: $A H^\dagger H Y \to A\, v\, h\, y$

Needed to obtain enhancement of diphoton signal

mixing angle: $\theta = \dfrac{Av}{4 m_h \Delta M} \gtrsim \sqrt{\mathrm{Br}_{\mathrm{h}\to\gamma\gamma}} \sim 0.05$

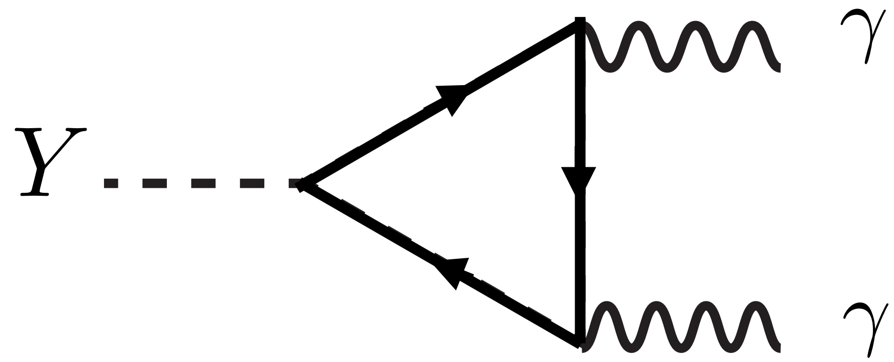
$$\Rightarrow \quad A \gtrsim 0.1\ \mathrm{GeV} \left(\frac{\theta}{0.05}\right) \left(\frac{m_h}{126\ \mathrm{GeV}}\right) \left(\frac{\Delta M}{\mathrm{GeV}}\right)$$

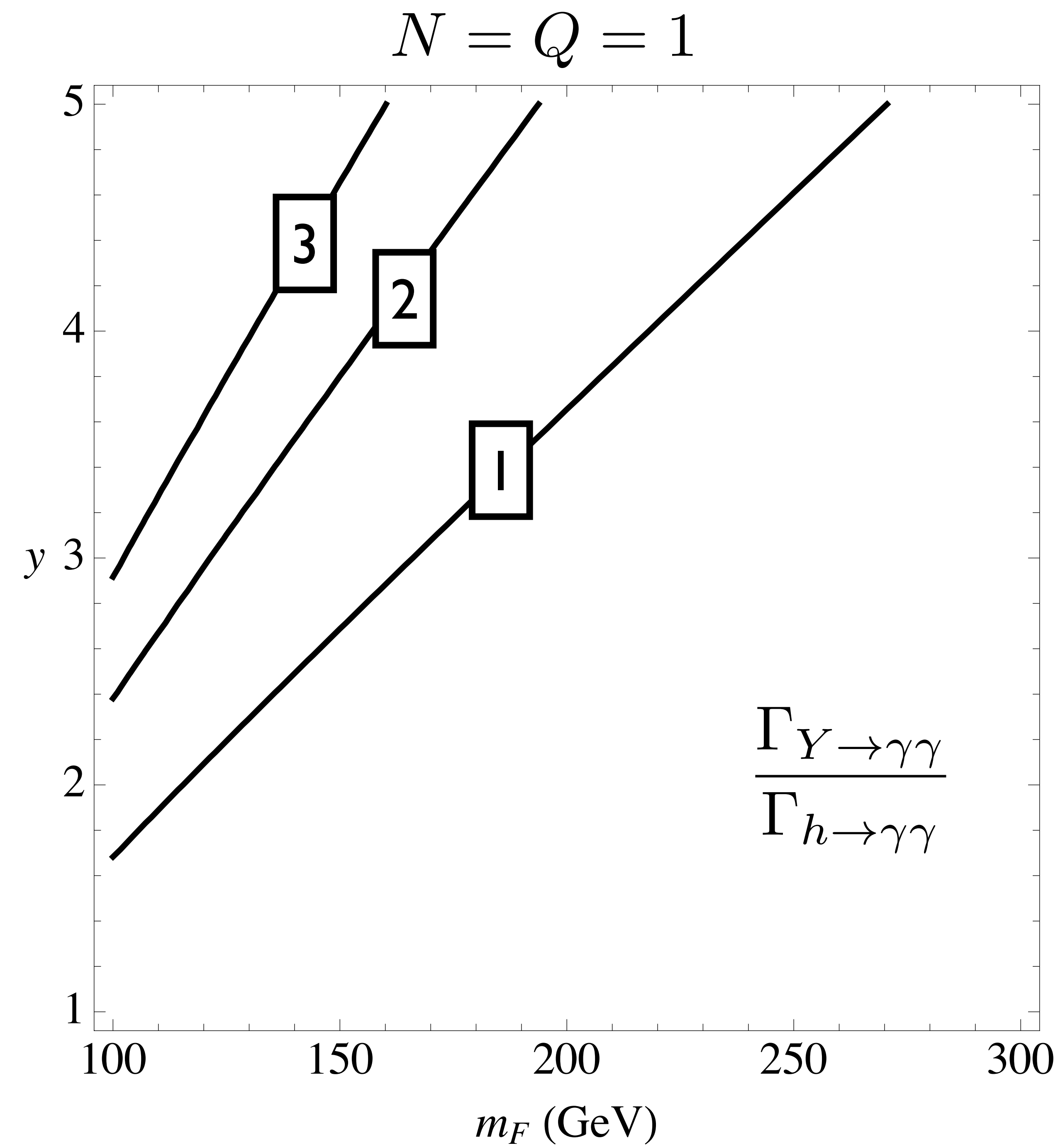
Easy to obtain required production rate of Y

Decays of Y

$$\frac{\Gamma_{Y\to\gamma\gamma}}{\Gamma_{h\to\gamma\gamma}} \gtrsim 1 \;, \quad \Gamma_{h\to\gamma\gamma} \simeq 10^{-5}\ \mathrm{GeV}$$

Needed to compete with $Y \to h^*$ modes



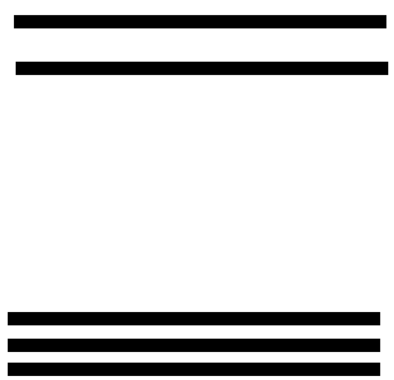


$$\Gamma_{Y\to\gamma\gamma} = \frac{N^2 Q^4 \alpha^2 y^2 m_Y^3}{256\pi^3 m_F^2} |A_{1/2}(\tau_F)|^2,$$

$$\simeq 10^{-5}\ \mathrm{GeV} \times N^2 Q^4 \left(\frac{y}{2}\right)^2 \left(\frac{m_Y}{125\ \mathrm{GeV}}\right)^3 \left(\frac{110\ \mathrm{GeV}}{m_F}\right)^2 .$$

Degenerate daughter

h
Y



$\} \ \Delta M \lesssim 1 \text{ GeV}$

$$\mathcal{L} \supset \frac{1}{\Lambda} Y F F$$

X

$$m_X \ll m_Y \lesssim m_h$$

Y produced in decay of Higgs

Requirements:

1. $\Gamma(h \to XY) \gtrsim \Gamma(h \to \gamma\gamma)$

2. $\Gamma(Y \to \gamma\gamma) \gtrsim \Gamma(Y \to h^* X)$

Minimal model

$$-\mathcal{L} = \frac{1}{2} m_X^2 X^2 + \frac{1}{2} m_Y^2 Y^2 + \lambda H^\dagger H X Y + y Y \bar{F} F$$

mass mixing and $h \to XY$

$h \to XY$ decay width

$$\Gamma_{h\to XY} \simeq \frac{\lambda^2 v^2 \Delta M}{8\pi m_h^2} = 10^{-5}\ \mathrm{GeV} \left(\frac{\lambda}{0.01}\right)^2 \left(\frac{\Delta M}{\mathrm{GeV}}\right) \left(\frac{126\ \mathrm{GeV}}{m_h}\right)^2$$

mixing angle: $\theta \simeq \dfrac{\lambda v^2}{2 m_Y^2} \simeq 0.02 \left(\dfrac{\lambda}{0.01}\right) \left(\dfrac{125\ \mathrm{GeV}}{m_Y}\right).$

Mild tuning to obtain light X: $\dfrac{\lambda^2 v^2}{4\hat{m}_Y^2} \sim O(5\ \mathrm{GeV}^2).$

Decays of Y

We need

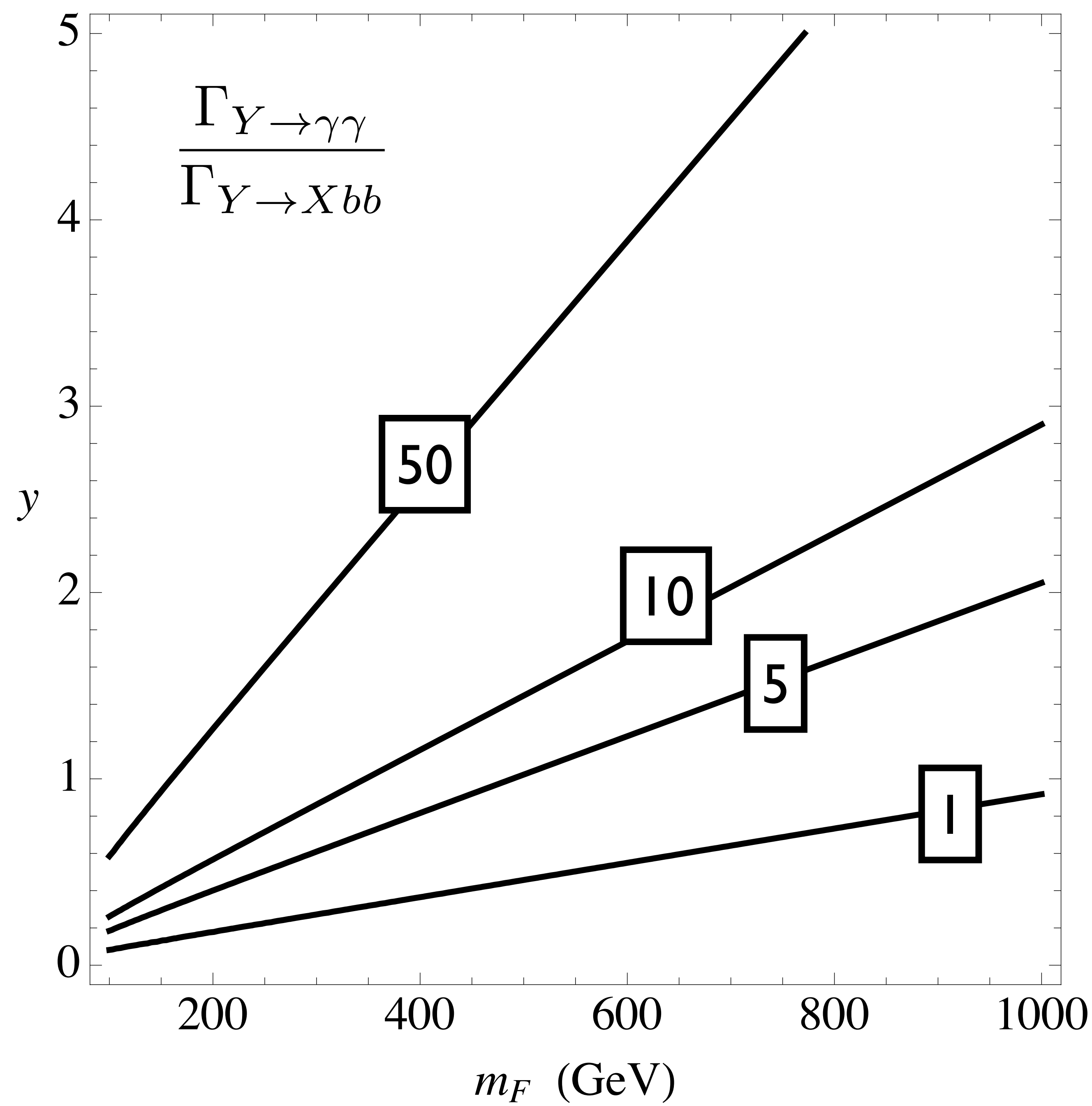
$$\Gamma(Y \to \gamma\gamma) \gtrsim \Gamma(Y \to h^* X)$$

Decay via off-shell Higgs is small, e.g.

$$\Gamma_{Y\to X\bar{b}b} \simeq \frac{3y_b^2\lambda^2 v^2}{256\pi^3 m_h}\left[\log\left(\frac{m_h}{2\Delta M}\right) - 2\right]$$

$$\approx 10^{-8}\ \mathrm{GeV} \times c \left(\frac{\lambda}{0.01}\right)^2 \left(\frac{126\ \mathrm{GeV}}{m_h}\right)$$

$N = Q = 1$



Decay to 2 photons

$$\Gamma_{Y\to\gamma\gamma} \simeq 5\times 10^{-7}\ \mathrm{GeV} \times N^2 Q^4 y^2 \left(\frac{m_Y}{125\ \mathrm{GeV}}\right)^3 \left(\frac{250\ \mathrm{GeV}}{m_F}\right)^2$$

Charged particles can be heavy!

Decays of X

Due to mixing, X couples to the charged particle

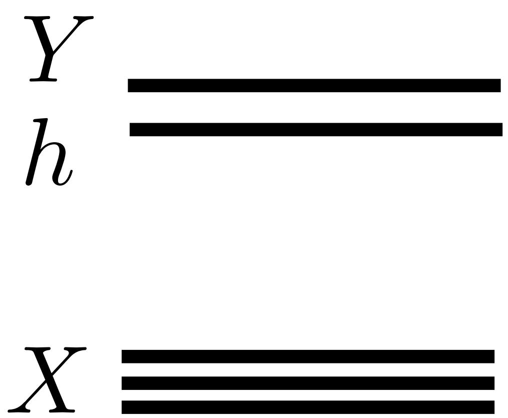
$$\frac{\Gamma_{X\to\gamma\gamma}}{\Gamma_{Y\to\gamma\gamma}} = \theta^2 \left(\frac{m_X}{m_Y}\right)^3$$
$$\simeq 2.5\times 10^{-11} \times \left(\frac{\theta}{0.02}\right)^2 \left(\frac{m_X}{0.5\ \mathrm{GeV}}\right)^3 \left(\frac{125\ \mathrm{GeV}}{m_Y}\right)^3$$

Long-lived

$$c\tau_X = 20\ \mathrm{m} \times \frac{1}{N^2 Q^4 y} \left(\frac{0.02}{\theta}\right)^2 \left(\frac{0.5\ \mathrm{GeV}}{m_X}\right)^3 \left(\frac{m_F}{250\ \mathrm{GeV}}\right)^2 .$$

Or, X could decay back to SM in jets, or to other light states, e.g. dark matter.

Degenerate mother



$\} \ \Delta M \lesssim 1 \text{ GeV}$

$$\mathcal{L} = \frac{1}{\Lambda} Y G G$$

$$gg \to Y \to hX$$

Gives an overall enhancement to the Higgs production rate

Not what is being seen in currently ...
but who knows with more data?

Experimental issues to understand

To mimic diphoton signal...

How small must ΔM be?

How light must X be?

For a large enough ΔM, should observe two nearby peaks in the diphoton invariant mass spectrum

Phenomenology of the light state X

... work in progress